Pavement Temperature and Corresponding Density Differentials

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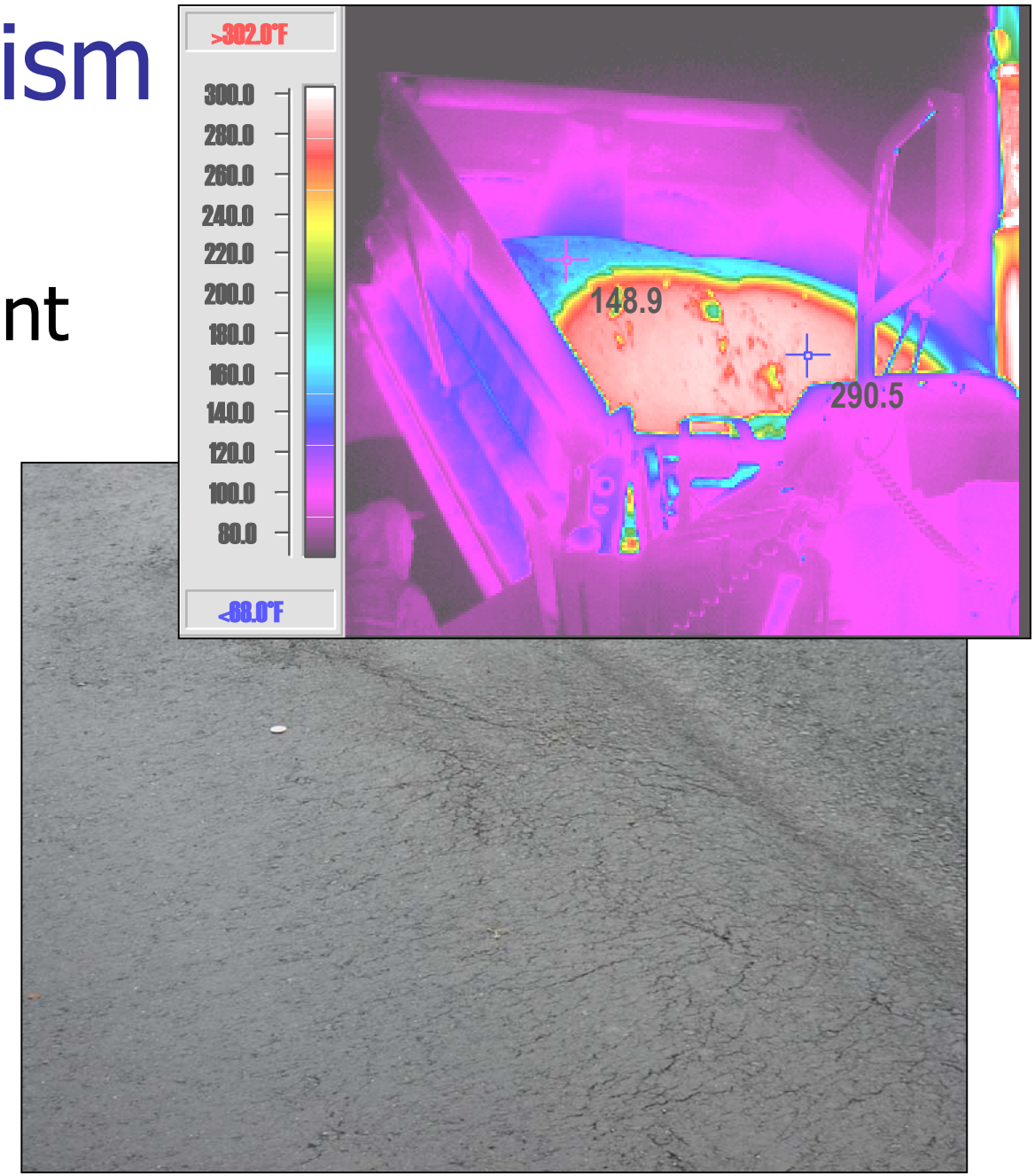
The Problem

- Localized areas of coarse surface texture
  - Due to temperature differentials and/or aggregate segregation
- Premature failure due to raveling, moisture damage, and fatigue cracking

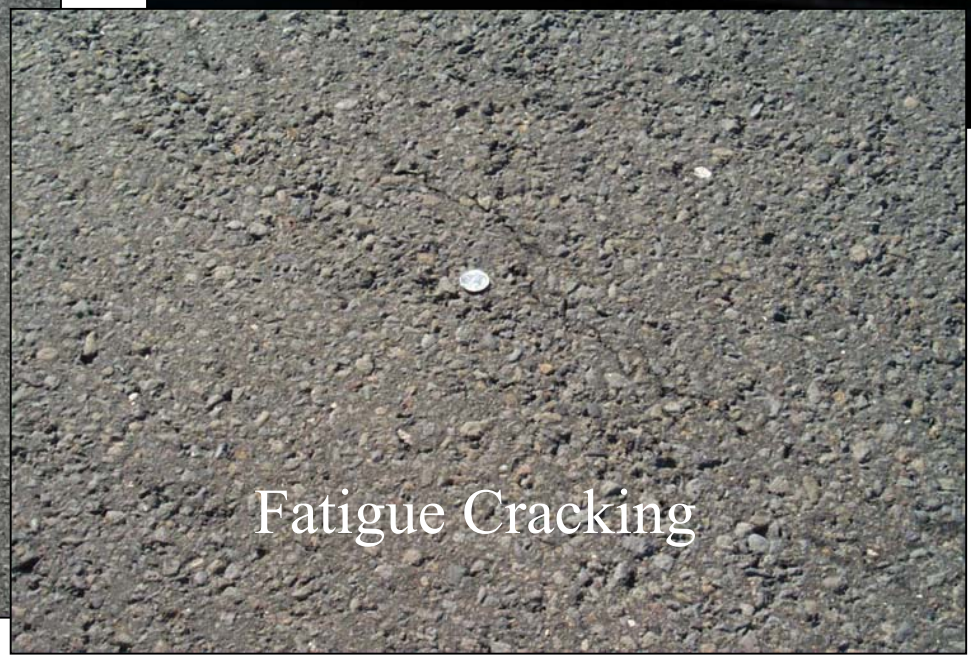
Damage Mechanism

- Placement of cooler HMA creates pavement areas near cessation temperature (about 175°F)
- No significant compaction occurs below cessation temperature

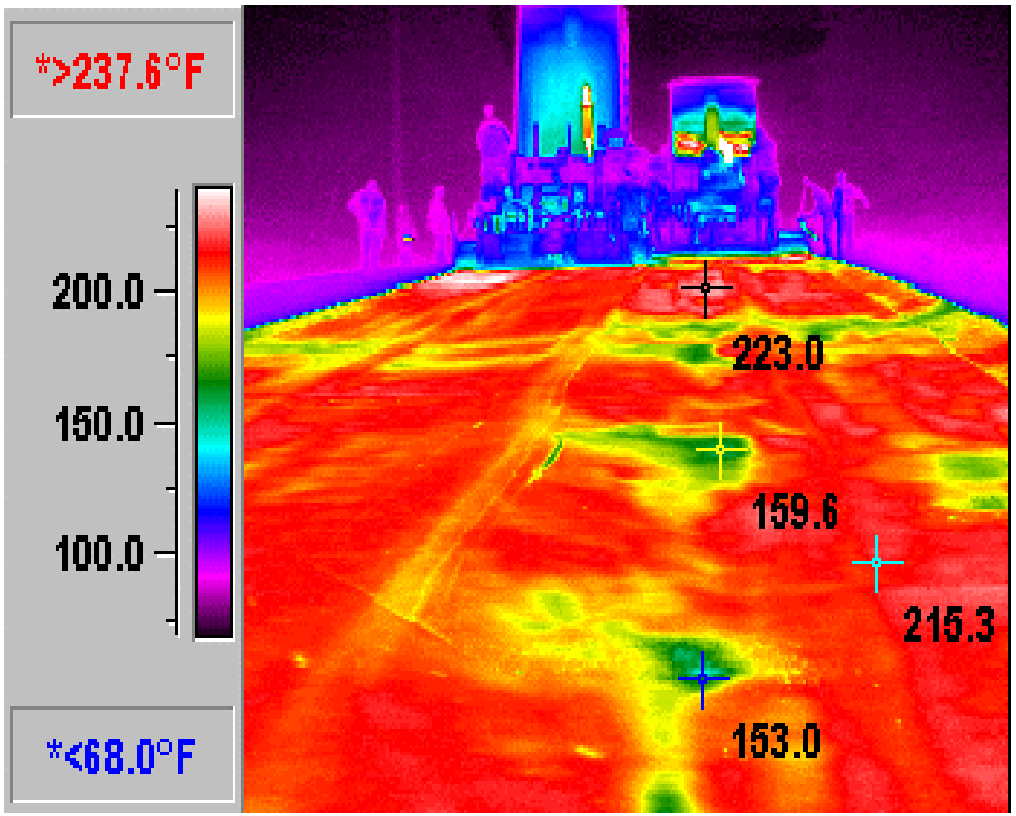


Pavement Effects

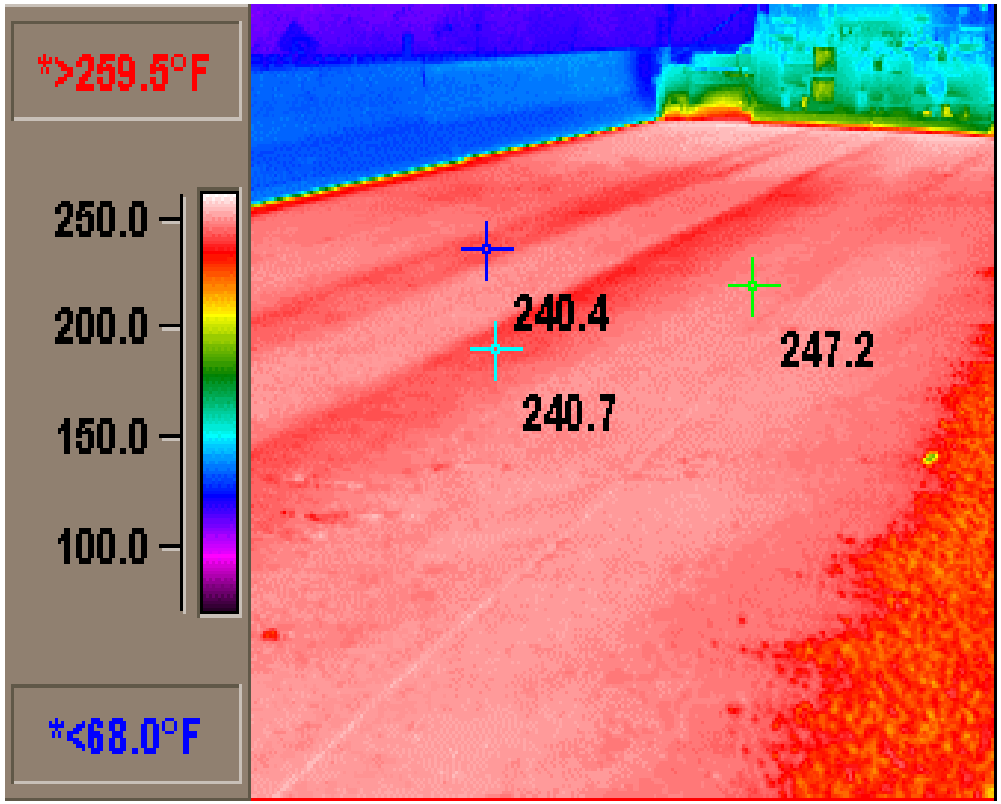
- 1% increase in air voids results in a minimum 10% reduction in pavement life



Temperature Differential Spots



Temperature Differential/ Aggregate Segregation Streaks



Background (1998-1999)

- Locate temperature differentials with infrared camera
- 1998 - Test for aggregate segregation, asphalt/aggregate segregation, and density differentials
  - 4 projects (early or late season)
- 1999 – Determine temperature differentials with respect to different material transfer devices/vehicles, haul times, environmental conditions, etc.
  - 36 projects (throughout entire paving season)

Conclusions (1998-1999)

- 1998 –
  - No significant aggregate segregation
  - Temperature differentials were significant on all projects and corresponded to low density areas
- 1999 –
  - Localized air voids increase with:
    - Increasing temperature differentials (> 25oF)
    - Increasing haul time
    - No remixing prior to placement

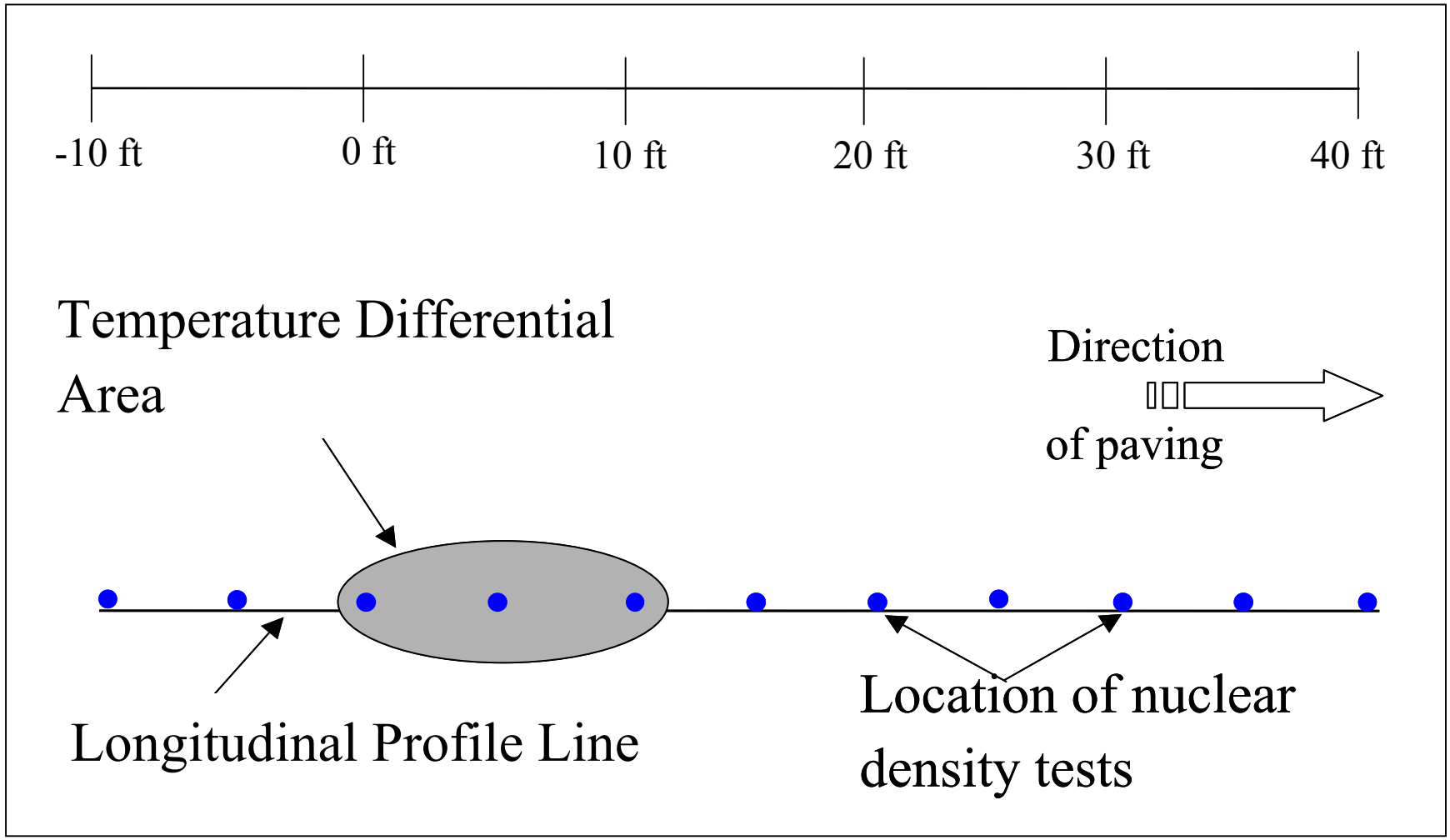
Conclusions Continued…

- 1999 –
  - Temperature differentials decrease with:
    - Remixing of the mix prior to placement
    - An increase in air temperatures (more time to compact)
- In general:
  - Concentrated areas of cooler hot-mix commonly occur under a variety of paving conditions
  - Good rolling practices can partially offset temperature differential-related compaction problems

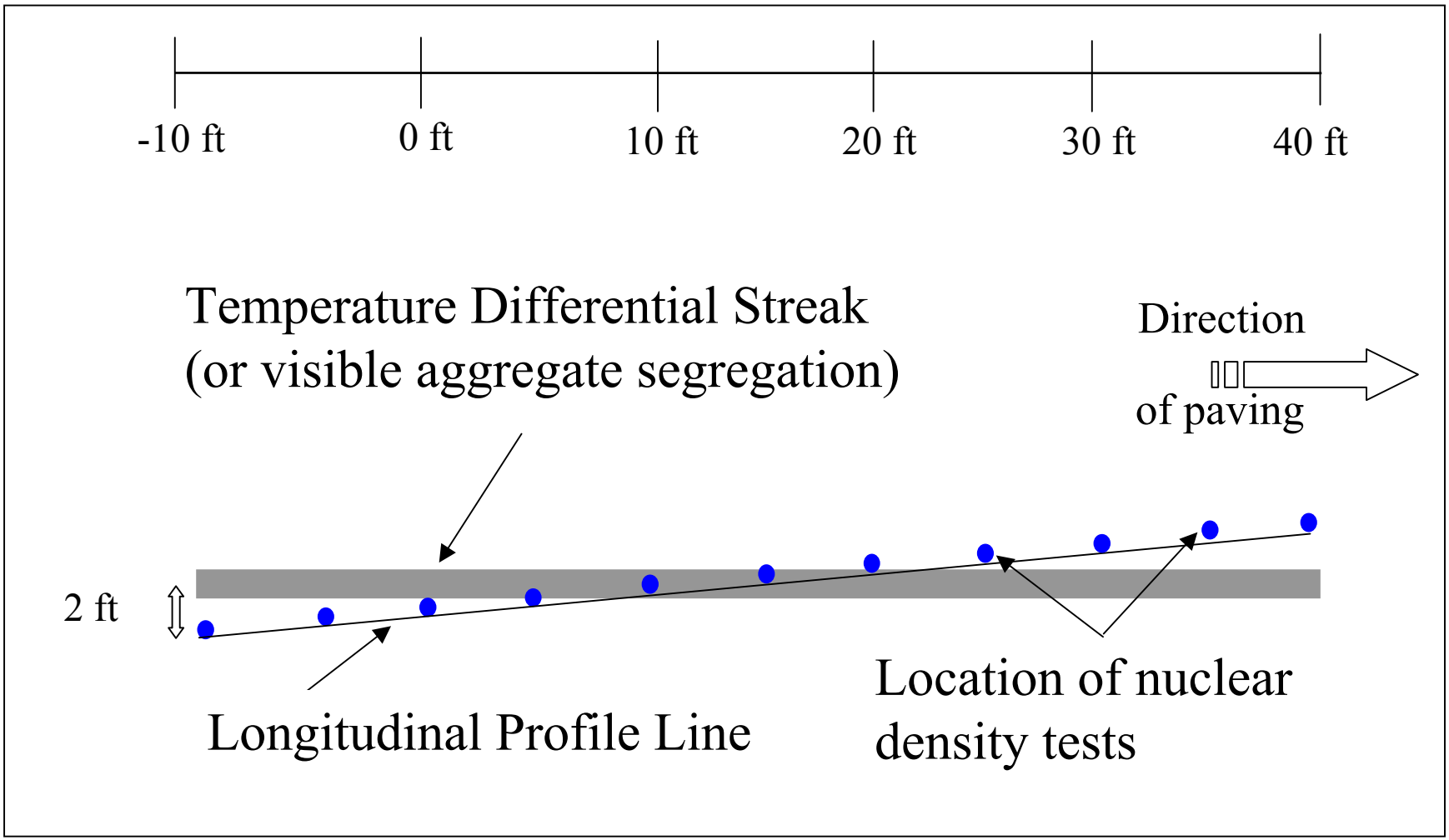
2000 Study Program

- Conduct infrared imaging (infrared camera, handheld temperature gun)
- Use surface temperatures to select longitudinal profile locations
  - 3 to 4 profiles per paving project (nuclear gauge)
  - Uniform and non-uniform mat surface temperatures
- Perform longitudinal density profile
- Calculate density differences for each profile
  - Maximum - minimum (<6.0 pcf)
  - Mean – minimum (<3.0 pcf)

Temperature Differential Spots

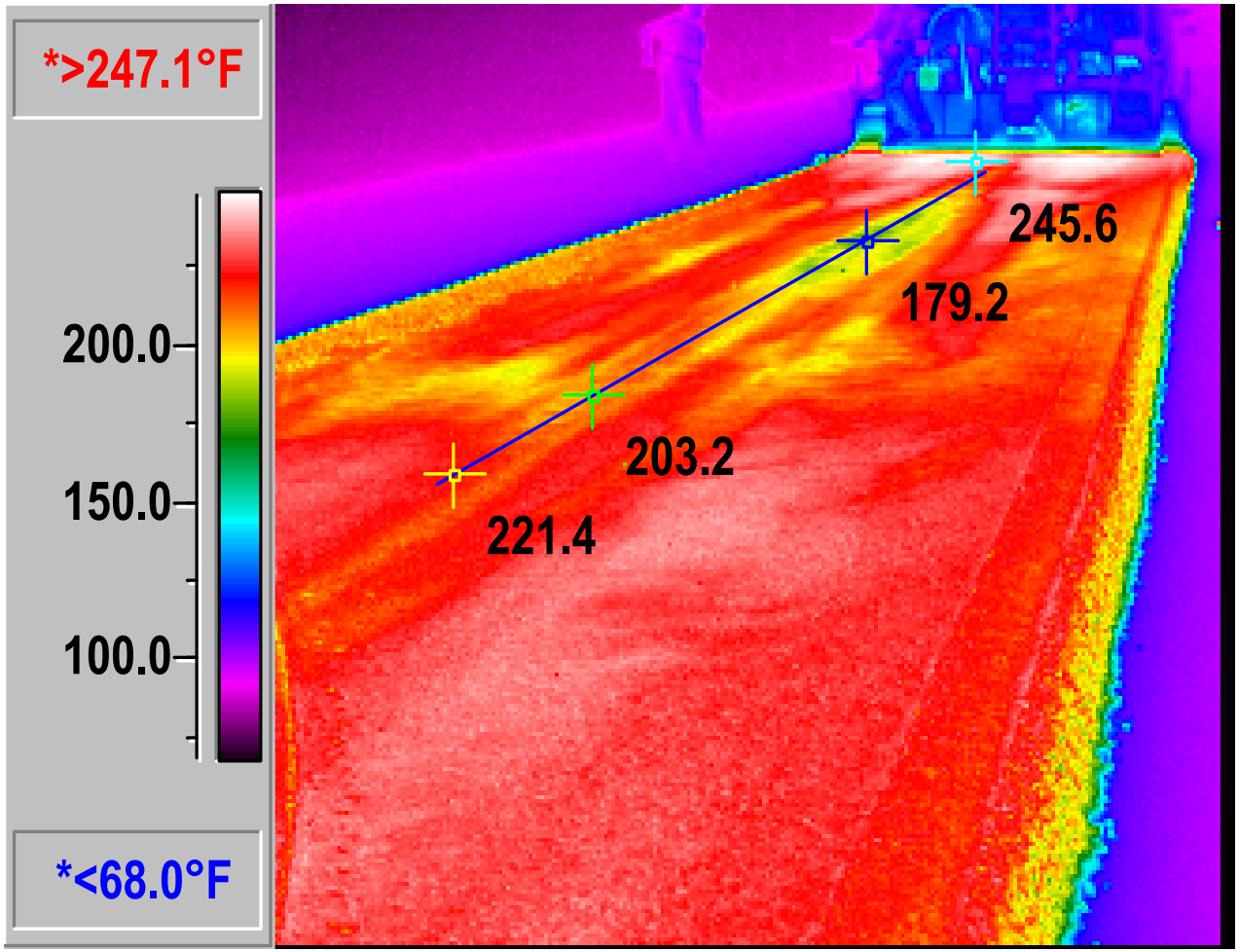


Temperature Differential Streak



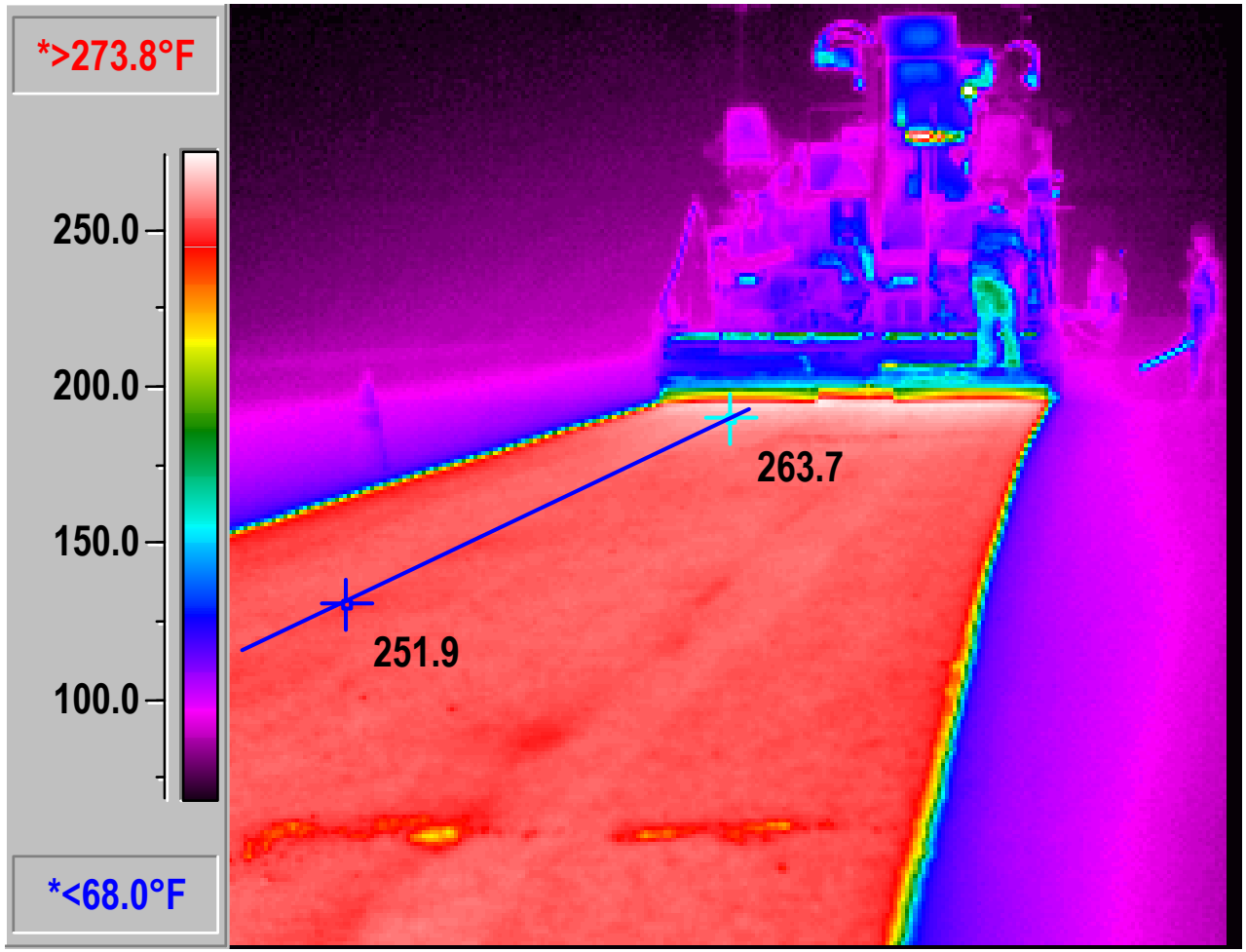
Failing Temperature/Density Criteria

- Readings
  - Mean 128.5
  - Max 133.5
  - Min 121.9
- Ranges
  - Max – Min 11.6
  - Mean – Min 6.6
- $\Delta T = 66^{o}F$



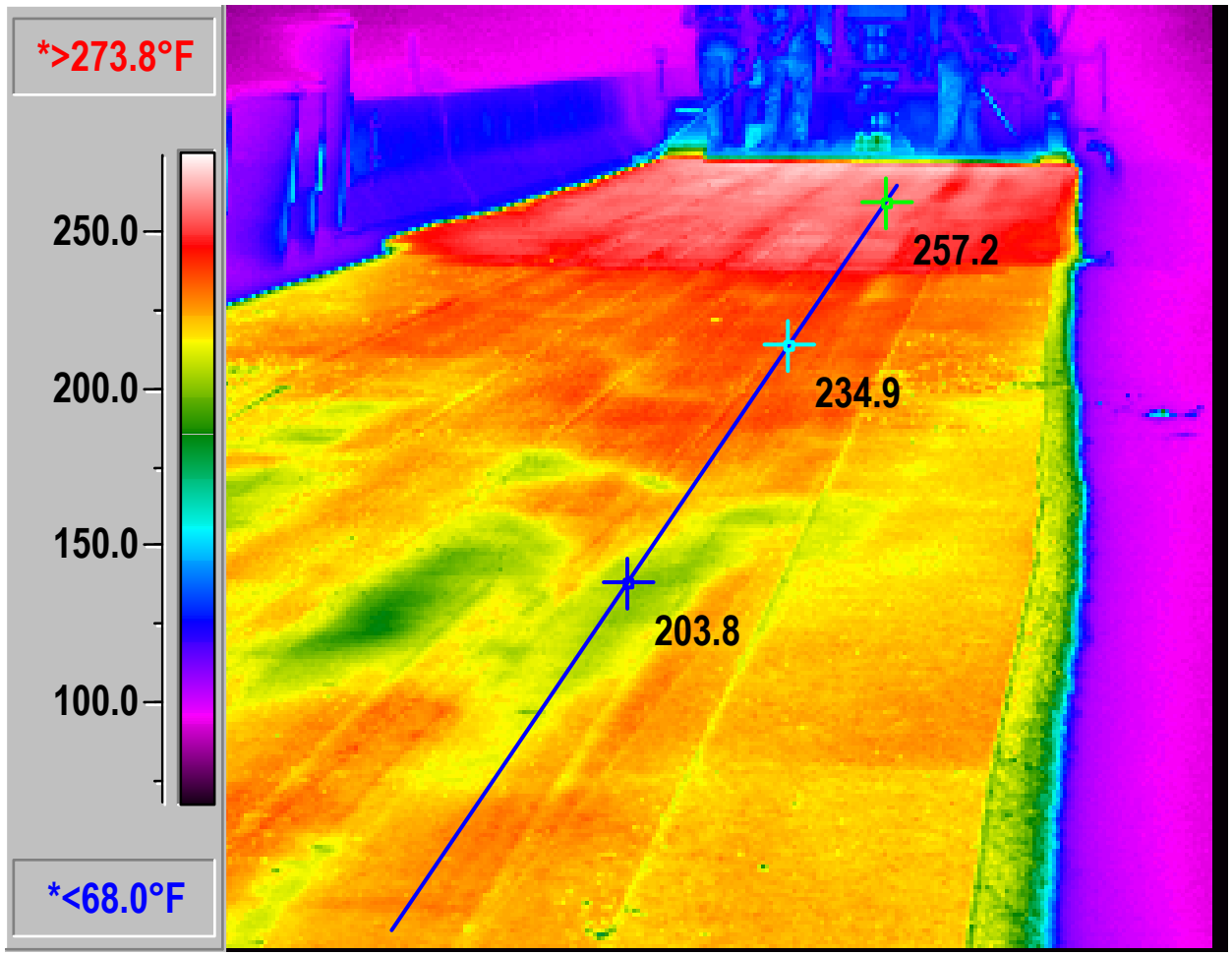
Passing Temperature/Density Criteria

- Readings
  - Mean 140.7
  - Max 142.9
  - Min 138.4
- Ranges
  - Max – Min 4.5
  - Mean – Min 2.3
- $\Delta T = 11^{o}F$



Failing Temperature/Density Criteria

- Readings
  - Mean 152.1
  - Max 155.7
  - Min 149.0
- Ranges
  - Max – Min 6.7
  - Mean – Min 3.1
- $\Delta T = 53^{o}F$

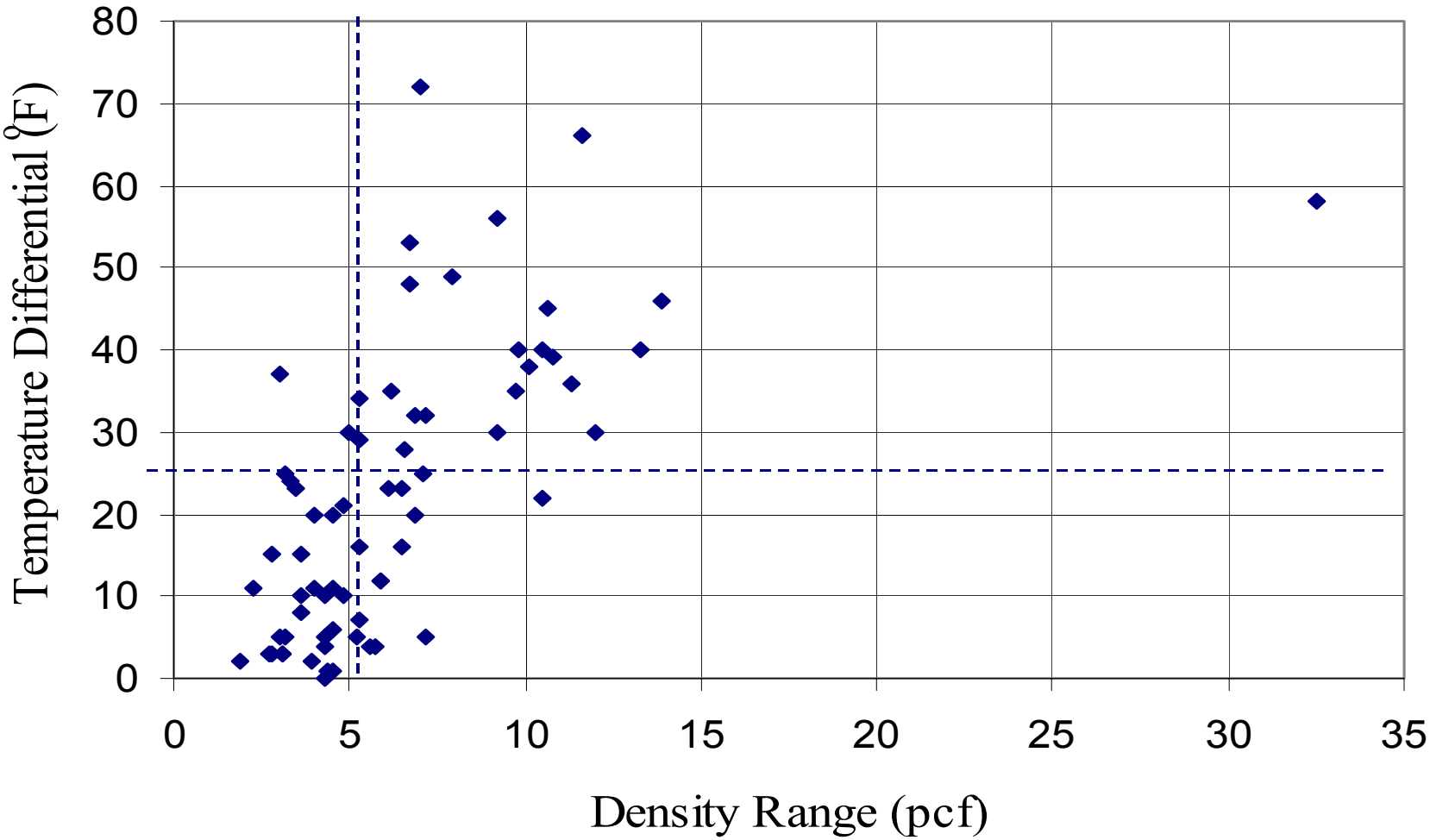


2000 Conclusions

- Calculate density differences for each profile
  - Max – Min < 6.0 pcf
  - Mean – Min < 3.0 pcf
- Criteria used for all types of mixes (WSDOT Class A, B, 12.5mm, 19.0mm, and SMA)

	$\Delta T \geq 25^{o}F$	$\Delta T < 25^{o}F$
Number of Profiles	28	41
Failed both density criteria	20	4
Passed both density criteria	3	33
Failed only high - low	3	2
Failed only mean - low	2	2
Percent passing	10.7	80.5
Percent failing	89.3	19.5

Density Profiles



Density Profiles

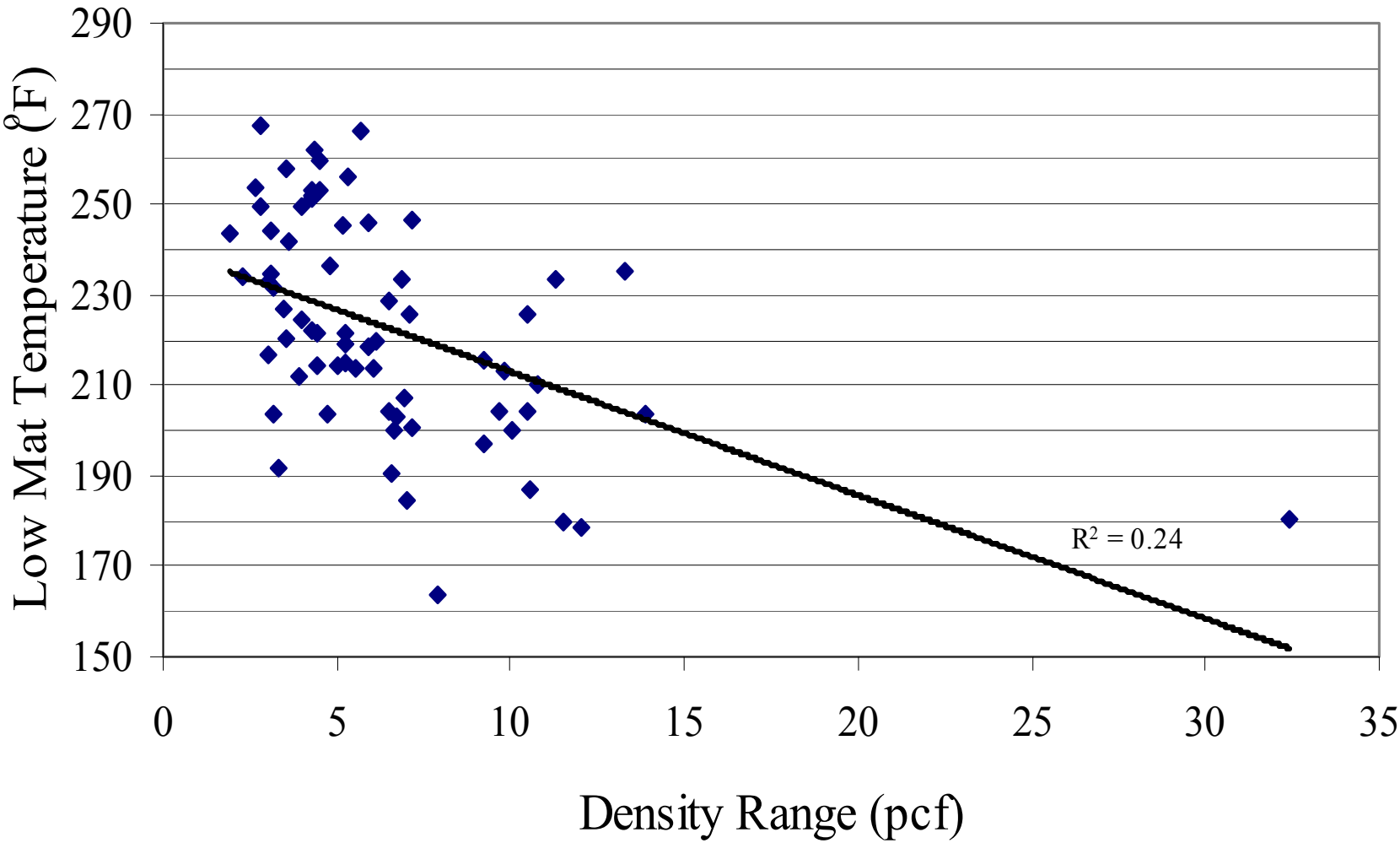
- 68% of the minimum densities within the density profile were below the minimum allowable according to WSDOT Specs (91% of MTD)
- 43% of the average densities below minimum
- 14% of the maximum densities below minimum

Density Criteria

Density Range Criterion				
Density Range	>5.0 pcf	>6.0 pcf	>7.0 pcf	>8.0 pcf
Percent of Projects	56.5%	42.0%	29.0%	21.7%
Percent below 91% density	76.9%	82.8%	90.0%	100.0%
Density Drop Criterion				
Density Drop	>2.0 pcf	>3.0 pcf	>4.0 pcf	>5.0 pcf
Percent of Projects	76.8%	40.6%	23.2%	17.4%
Percent below 91% density	75.5%	85.7%	93.8%	100.0%

- Example: the density range exceeds 5 pcf in 56.5% of the profiles. Of this 56.5%, 76.9% of the minimum densities in the profile are below 91% MTD.
- Therefore, the 6 and 3 pcf criterion captures the differential densities as well as the densities below 91% MTD over 80% of the time.

Low Mat Temperature



Project Comparisons (1999-2000)

	Number of Projects with Typical ΔT		
Equipment	$<25^{o}F$	$\geq 25^{o}F$	Total
No MTV	0	9	9
Blaw-Knox MC-30	3	8	11
Paddles operating	3	4	
Paddles not operating	0	4	
Roadtec Shuttle Buggy	10	1	11
Cedarapids MS-3	1	1	2
Windrow Elevator	13	5	18
Cedarapids MS-2	9	3	
Other Windrow Elevator	4	2	
CMI MTP-400	1	0	1

Project Comparisons (1999-2000)

	Number of Projects with Typical ΔT			QA Densities			Average Haul	Average Temperatures (°F)		
Equipment	≤25°F	>25°F	Total	Number of Tests	Average	Standard Deviation	Time (min)	Mat	Air	Surface
No MTV	0	9	9	1405	93.19	1.56	13	257	69	98
Blaw-Knox MC-30	3	9	11							
Paddles operating	3	4		1295	93.43	1.77	18	260	63	84
Paddles not operating	0	4		790	93.98	1.94	8	253	66	77
Roadtec Shuttle Buggy	10	1	11	2430	92.82	1.25	36	251	64	81
Cedarapids MS-3	1	1	2	480	93.42	1.27	24	253	58	75
Windrow Elevator	13	5	18							
Cedarapids MS-2	9	3		2735	93.34	1.48	22	243	79	104
Other Windrow Elevator	4	2		1420	92.86	1.39	28	260	83	108
CMI MTP-400	1	0	1	425	93.03	1.25	12	240	63	65
Windrow Elevator/MC-30	1	0	1	485	92.98	1.37	15	250	55	60

Bottom Line

- Temperature and density differentials can be a significant issue on paving projects. Approximately ½ of projects (28 out of 53) studied during 1999 and 2000 regularly had temperature differentials $\geq 25°F$.
- Following three years of data collection and analyses, differential densities resulting from cooler than desirable mix can be significant. How significant?

Bottom Line

Percent of Rice Density Mean	Mix Air Voids @ Density Mean	Mix Air Voids @ Mean – 3 pcf	Mix Air Voids @ Mean – 6 pcf
95%	5.0%	7.0%	9.0%
94%	6.0%	8.0%	10.0%
93%	7.0%	9.0%	11.0%
92%	8.0%	10.0%	12.0%

(1) 155 pcf Assumed Rice Density; (2) Long Term WSDOT Average 93.1%

Pavement Tour

- Tour of the majority of the infrared projects
  - 43 out of 53
- Over 2,000 miles traveled
  - Infrared projects covered approximately 410 miles
- Distresses documented for any pavement that exhibited low-density areas (random or cyclic)

Examples of Pavement Distress

Cyclic Patterns of Low-Density

Conclusions

- Same general trends as what was seen in 1998 and 1999
- Normal QA does not capture the occurrence or severity of density differentials
- Density profiles can determine the effects of temperature differentials
  - Can be used as a quality control tool to minimize or eliminate density differentials

Conclusions Continued…

- Pavement tour shows that density differentials are a significant problem
  - Many pavements exhibited random and cyclic areas of low-density
  - Need to continue to monitor the condition of these areas

2001 Shadow Specification

- An agreement was made between the Contractors of APAW and WSDOT to perform density profiles during the 2001 construction season
- Density profiles were run on 20 projects
  - Approximately 200 profiles run
    - 121 had density and temperature information

2001 Shadow Specifications Results

	$\Delta T \geq 25^{o}F$	$\Delta T < 25^{o}F$	$\Delta T = ?$
Number of Profiles	62	59	35
Failed both density criteria	26	14	13
Passed both density criteria	28	40	19
Failed only high - low	3	1	3
Failed only mean - low	5	4	0
Percent passing	45.0 (10.7)	68.0 (80.5)	54.0
Percent failing	55.0 (89.3)	32.0 (19.5)	46.0

( ) results from 2000 study

2002 Specification

- WSDOT is implementing a specification to locate and test density differentials
- Disincentive of 15% of the ACP unit price if density differentials are located
- Will be performed on 4 projects in 2002

2002 Testing Procedure

- Use handheld temperature gun to locate temperature differentials
- 4 or more locations per lot will trigger testing of specific areas
- If the density in these areas are 2% less than the minimum allowable density, then the Contractor is penalized
- Testing (and penalty) is continued until temperature differentials do not exist

Potential 2003 Specifications

- Include on all paving projects
- Modification of selection criteria
  - All locations below 91% MTD
  - Four or more locations triggers testing change
- Abandon random sampling and use systematic sampling for determining pay factor

Further Work

- Pavement Tour
  - Continue evaluating infrared projects for distress
- In-place density
  - Does the entire pavement need to be compacted to 93% of MTD?
  - Where's the break between what is acceptable and not acceptable?
  - Does the environment factor in on density?

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